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Sunlight Qualities in Dwellings

A new computational analysis tool

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``Architectural harmony with natural systems - including natural light - is essential to the wellbeing of building occupants'' (Shrum, 2017). A preliminary study of existing daylight recommendations in standards and sustainability certificates, applied in Denmark, revealed a neglectance of the importance of receiving direct sunlight in dwellings. The qualities of sunlight were defined through a modest qualitative analysis, resulting in five parameters: Sunlight Hours, Winter Sun, Morning Sun, Golden Hours and Magic Moments. These were defined as specific time periods supported by research on the visual and non-visual effects on well-being. The parameters were subsequently translated into a parametric analysis tool, using design application Rhinoceros 3D and elaborating on a new usage of the design software Ladybug Tools. This analysis tool is predicted to be of high use to identify problematic apartments in the architectural design phase, to compare different design proposals and to meet the individual needs of new occupants.

Keywords: *Nordic daylighting, sunlight in dwellings, sunlight qualities, parametric design, daylight design*

INTRODUCTION

This paper is written on the background of a master thesis in Lighting Design at Aalborg University in Copenhagen by the two first authors.This paper includes the most essential and significant findings of developing a new usage of a parametric analysis tool for ensuring better sunlight exposure in dwellings.

The paper takes departure from investigating the limitations of the most common daylight metrics in relation to the characteristics of Nordic daylight and especially the neglectance of the importance of direct sunlight exposure in dwellings, found in building standards and sustainability certificates, commonly used in Denmark.

Daylight, and especially sunlight, can be considered as a limited resource in the dense urban areas in the Northern latitudes. People in the Western world spend most of their time indoors and since sunlight is proven to be necessary for our health and well-being (Whitsett & Fajkus, 2018), it is crucial that we design residential buildings with focus on direct sunlight exposure. The current daylight metrics mainly focus on the intensity and distribution of daylight, additionally addressing glare and the amount of sunlight hours.

In the Northern latitudes the dynamics of daylight are revealed not only in the variations in intensity, color temperature and in the ever-changing cloud coverage, but also with vast seasonal differences. In Copenhagen the daylight hours vary from around 7 hours at winter solstice to 17 ½ hours at summer solstice [3]. To design living environments that can enhance the many qualities that come with the presence of direct sunlight, there is a potential to develop a new analysis tool, which addresses these qualities in the early architectural design phase. Therefore, we raise the following questions: *How can qualities of Nordic sunlight in dwellings such as apartment buildings be defined? And how can these qualities subsequently be translated into a parametric analysis tool, with the aim of improving the daylight design of our homes?*

Qualities of sunlight

Sunlight is proven to have a positive effect on our health and well-being. Matt Fajkus and Dason Whitsett argue that sunlight is not merely beneficial to humans but is an absolute necessity (Whitsett & Fajkus, 2018). As we humans on average spend up to 90% of the time indoors (Klepeis et. al, 2001), it is crucial that we ensure direct sunlight exposure in our living environments. Exposure to sunlight affects our physical health positively in numerous ways. The UV parts of sunlight work antiseptically and are deadly to some bacteria (Downes & Blunt, 1877), even in interior spaces with low-iron window glass, enabling penetration of the UVb parts of light (Volf, 2013). Under the same conditions, our bodies are able to produce vitamin D (Tragenza & Wilson, 2011). In the Northern latitude of 56°, where Copenhagen is located, the UVb light is present from April to September, however fortunately vitamin D can be stored by our bodies for the winter period (Volf, 2013). Vitamin D is for instance crucial for production of calcium for strong bones, whereas a lack of vitamin D can be related to a number of health issues such as depression, cancer, diabetes, high blood pressure, multiple sclerosis, and rheumatoid arthritis (Whitsett & Fajkus, 2018). Exposure to sunlight, with emphasis on the short-waved blue light, helps our bodies to regulate our circadian rhythms, the daily eating and sleeping patterns (Boyce, 2014). The intense exposure to light has also an important relation to the ganglion cell in the eye, which regulates two closely related hormones. Serotonin, which is the happiness hormone, affecting mood, activity, appetite, pleasure and memory. The second hormone is the sleep hormone melatonin, which is synthesized from serotonin (Volf, 2013).

The presence of sunlight also affects psychological well-being and mental health. The less amount of daylight and sunlight hours is found to be a cause for common psychiatric illness known as seasonal-affective-disorder, SAD. This depressive condition is estimated to affect around 14 million people in Northern Europe (Tragenza & Wilson, 2011). On the other hand, the exposure to direct sunlight is found with positive physiological effects and is generally appreciated in dwellings during cold winter months, welcoming occupants with a sensory feeling of warmth and high level of brightness, stimulating the eyes (Whitsett & Fajkus, 2018; Tragenza & Wilson, 2011). Moreover, the direct sun rays are found to affect the perceived atmosphere, making rooms bright and cheerful and creating a therapeutic, health-giving effect (Littlefair, 2001). The direct sunlight in an interior architectural space is also contributing to the visual appearance of the space, with sunlight patches and reflections of light appearing, disappearing and moving in the space; and creating temporary light-zones (Madsen, 2006). Direct sunlight can create a quality of enhancing an architectural space by extending or decreasing the dimensional appearance e.g. depth of a space. Moreover, the three-dimensionality of objects, characterized by distinct shadow patterns and highlights appear with a presence of diffuse (skylight) and direct light (sunlight) components. This light quality has been referred to as *light modelling* and has been a subject for numerous studies (Zakina, 2016; Hansen & Mathiasen, 2019).

Standards and certificates

For many years, the Daylight Factor has been one of the most used and well-known metrics worldwide. This metric only includes the skylight component of daylight, including the external and internal reflected skylight [7]. Thus, the sunlight component is not included in this metric.

During the last decade, a series of new daylight metrics have been introduced. The main evolution is the introduction of climate-based daylight metrics, which takes into account the intensity of the daylight at a given site, based on standardized weather data, thus including the contribution from the sunlight component of daylight. Among the most common climate-based daylight metrics today are the *spatial Daylight Autonomy (sDA)* [1] and the *Annual Sunlight Exposure (ASE)* [2]. Common for the metrics is that they are made to ensure an accurate amount of daylight within a room. The *DF* and the *sDA* metrics document a sufficient amount of daylight, whereas the *ASE* sets upper limits of daylight intensities to limit glare and overheating.

The development of the metrics has included visual and qualitative assessments of the interior spaces in order to determine acceptable values (Hechong, 2012). However, the *sDA* and *ASE* were evaluated based on room types such as offices, schools and libraries where visual tasks are carried out on a daily basis, but the *sDA* metric is also used for documenting daylight in dwellings.

Looking into daylight recommendations in the *Danish Building Regulations* [10], the new *European Daylight Standard* (European Standard, 2018) and a series of sustainability certificates *DGNB* (Green Building Council Denmark. 2016), *BREEAM* (BRE Global Ltd, 2016), *LEED* (U.S Green Building Council, 2018) and *WELL* (Delos Living LLC, 2014), two main conclusions could be drawn. Firstly, the same recommendations are often set for both office and living environments - except for glare, which is only addressed for offices. Secondly, little focus is set on ensuring direct sunlight in the living environments. Out of the six reviewed standards and sustainability certificates only the *European Daylight Standard* and *DGNB* set requirements for minimum sunlight hours in living environments. There is found to be a general neglectance of the importance of receiving direct sunlight in dwellings.

Urban densification

The major cities around the world are going through urban densifications. The main factors affecting the urban densification are: birth surplus, longer life expectancies, change in family constellations and net immigrations from other parts of the country. In general, more and more people choose to live in the city, due to appealing lifestyles, larger number of activities and broader job opportunities (Christensen, 2016). As an example, the Danish capital, Copenhagen, has increased its population with approximately 10.000 inhabitants per year since 2008 (Københavns Kommune, 2018).

When the population increases, a higher housing demand follows, which often results in densifications of existing built areas along with expansions of the cities. The increased densification of urban areas has consequences for the daylight in the buildings, as the daylight intake in interior spaces is dependent on the surrounding context. The denser the urban context, the less direct daylight, both from the sky and the sun, is available.

In Nordic regions the combination of a dominant overcast sky condition and low sun elevation angles during the winter period (10° in Copenhagen at solar noon at winter solstice), results in limited daylight availability with overshadowing as an obvious problem in the context of dense cities (Strømann-Andersen & Sattrup, 2011). Therefore, the subject of direct sunlight in dwellings from an inhabitant perspective was chosen to be investigated, with the aim to support the literature findings and identify new qualities, which are appreciated by the residents.

ANALYSES TO DESIGN PARAMETERS

Qualitative analyses

To define the qualities of sunlight in dwellings, a series of modest qualitative analyses were conducted.

The analyses took departure from a phenomenological approach, studying the residents' subjective experience of direct sunlight in their homes. As the German philosopher Böhme states, if architecture shapes the space, one must move about in these spaces in order to evaluate them and must be physically present (Böhme, 2002). For the first set of data collection, photo-survey was chosen. The participants were asked to photograph or record a short video sequence at their homes, when sunlight made an impression on them. The *reflexive photography* (Close, 2007) research technique was applied to gain knowledge into participants' personal reflections, using a short questionnaire form including information about time, date, location as well as a detailed description of the photographs. The data was collected during the weeks of March and first week of April in 2019. The photo-survey consisted of 20 images and 7 statements from 11 female and 1 male participants, ranging in age between 26-66 years, with the mean age of 41,5 years. The participants were located in Denmark (9), Sweden (1), Norway (1) and the Netherlands (1). Prior to the data analysis of *reflexive photography*, an additional visual analysis method was applied. A subjective descriptive visual analysis of the participants' imagery, addressing a simple question: *Which sunlight qualities appear to be present in the captured photographs?* (Figure 1).

To gain more in-depth knowledge on the subjective experience of the possible qualities of direct sunlight inflow in dwellings, a second qualitative analysis in form of three *semi-structured video interviews* (Bjørner, 2015) were conducted. The interviews were recorded in the participants' own home environments to register the surroundings and enable the interviewees to best reflect and recall their experience in relation to daylight and sunlight as a phenomenon in their homes. The interviews were transcripted and manual coding conducted by two of the authors separately, identifying key findings, using the meaning condensation method within content analysis (Bjørner, 2015). The participants were all female, one of them in her mid 20s and two others in their 50s. The interviews were carried out in March in 2019 with durations between 10-25 minutes, two of them in apartment buildings in Copenhagen and one of them in a house, located in a suburban area, 50 km from the capital.

Figure 1
Photograph from photo-survey with following description: “Sometimes early in the morning, the rising sun shines directly into my kitchen and living room, which is one space. I love it. I love the images it creates on the wall and the fact that it fills the space with warm reflected light. On this image it's orange, but it can have so many different colour tones, from soft pink to blurred multi-colored orange.” — Merete, Copenhagen

Keywords from the three qualitative analyses were formed and collected for further analysis (Figure 2). To structure and analyse all the qualitative data, *affinity mapping* method, which can be ideal for grouping data [4], was applied. The main keywords formed the basis of the mapping exercise. Numerous keywords in the analysis were identical or in close relation to the sunlight qualities identified in the literature study. The following three additional qualities emerged from the qualitative analysis: 1) sunlight is informative, providing information about orientation, weather, time of the day and is an indicator of season; 2) sunlight highlights the connection to nature and to the outside; 3) sunlight can be a source of visual expression and wonder in form of play of light through shadows and change in color.

All the keywords were thereafter evaluated in relation to each other and groupings were formed, resulting in five categories with specific titles assigned. The five categories represent the main qualities of Nordic sunlight derived from the series of qualitative analysis. The categories are: *Sunlight Hours*, *Winter Sun*, *Morning Sun*, *Golden Hours* and *Magic Moments*. The sample size of the qualitative analysis was modest, due to time constraints, and therefore future studies are proposed to further validate the findings. However, these five categories formed the basis of the definition of the five design parameters, supported by references to the literature research, carried out in the first stage of this project.

Golden Hour

- ▲ Variations and dynamics
- ● Different color tones
- ● Orange light
- ▲ Colored light
- ● Beautiful evening sun
- ● Beatuiful reddish light
- ■ Colored light

Magic Moments

- ▲ Sunlight entering corners, where unexpeted
- ■ Curiosity
- ● Reflected light
- ● Light can be catched and reflected
- ■ Reflections
- ▲ Magic moments
- ▲ Reflected light
- ▲ Stripe of sunlight
- ▲ More quality than quantity
- ● Playing with the movements of light
- ▲ Yellow facades, beautiful sun-like reflected light

- ● Visual analysis of photographs
- ■ Photo descriptions
- ▲ Video interviews

Figure 2
Extract of the affinity mapping exercise: key words and key phrases from the three qualitative analyses, forming the basis of the two sunlight parameters Golden Hour and Magic Moments.

Five sunlight parameters

The design parameters address solely the positive effects of direct sunlight on our physical and physiological well-being. They are defined with measurable relations to time continuum and the Sun movement in order to be applied in a parametric design programme.

Sunlight Hours is defined as the amount of time when direct sunlight inflow is present in a given architectural space, with the emphasis on the positive effects. This parameter is the basis and departure for all five. Direct sunlight has a large amount of qualities and benefits on our physical well-being: including production of vitamin D, related to the prevention of numerous diseases (Whitsett & Fajkus, 2018); deadly to some bacteria (Downes & Blunt, 1877); triggering our circadian rhythms; regulating our happiness hormone serotonin and affecting our sleep hormone (Volf, 2013; Boyce, 2014). The physiological well-being is impacted by: providing a sensory experience of warmth (Whitsett & Fajkus, 2018); creating rich light modelling of objects and architecture (Zakina, 2016; Hansen & Mathiasen, 2019); impacting the perceived atmosphere in the space to be positive, therapeutic and cheerful (Littlefair, 2001); being informative and with indications to orientation, weather, time of the day and season; highlighting the connection to nature and outside; being a source of visual expression and wonder in form of play of shadows and change in color.

Winter Sun is defined as the sunlight hours during the period from the beginning of November to the end of February. The time period was defined on the background of the astronomical season and consideration of the Sun position during winter solstice being in December and not in mid-season. Therefore November month was added. The presence of direct sunlight, affects the physiological well-being positively by: contributing to the prevention of the seasonal-affective-disorder (Tragenza & Wilson, 2011); providing a sensory experience of warmth, welcomed in contrast to the cold weather outside (Whitsett & Fajkus, 2018); creating rich light modelling of objects and architecture (Zakina, 2016; Hansen & Mathiasen, 2019), where possible, with low sun angle penetrating deep into the building; being informative and with indications to season, characterized with low sun angle and long shadow patterns.

Morning Sun is defined as a time period between 6 am and 9 am, where the direct sunlight is present in the dwelling. The time is related to Danish word for morning '*morgen*' defined as 6 to 9 am and the most common wake-up time 6:50 am in Denmark was also considered. The morning sun is found to have a positive impact on our physical well-being by: triggering our circadian rhythms, influencing eating and sleeping patterns and affecting our morning alertness (Volf, 2013; Boyce, 2014). In an architectural context the morning sun has been a design element, dating back to 1st century BC. The Roman architect Vitruvius emphasized the morning light to be suitable for bedrooms and libraries (Rowland & Howe, 2001).

Golden Hours are defined as the time periods around the transition of day and night, when direct sunlight is entering an architectural space. The period is defined by Sun elevation angle between 0 and 6 degrees above the horizon. This phenomenon of transition between day and night and the change of color of the sunlight, changing from around 5000 K to color temperatures below 3000 K (Dubois et. al, 2019), is characterized with a palette of colors yellows, oranges, pinks, purples and red tones. The duration of the golden hour is dependent on the latitude on the Earth and the season. In Copenhagen, the duration of golden hour varies between 48 and 77 minutes [5]. This criterion is expressed in several positive effects for our physiological well-being, hereunder: being informative and with specific indications to time, marking the transition of day and night; being a source of visual expression and wonder in the form of coloring the sky in a palette of colors, triggering a positive emotional response. This parameter can be described in relation to time and geometry, however the expression can vary drastically, depending on the amount of particles in the atmosphere and cloud coverage.

Magic Moments are defined as the time periods with direct sunlight, entering a space with a maximum duration of 30 minutes. This was a finding from an interview and supported by examples from architecture. For instance, Jørn Utzon designed his house Can Lis at Mallorca with a small specific detail, a daylight opening, that would be marking a seasonal change, as the change in the Sun's position on the sky. The design ensured to exclude a sun stripe entering a space during June, though otherwise present throughout the year (Mathiasen, 2015). The aim of this parameter, *Magic Moments*, is to enable occupants to discover these special moments of temporary sunlight patches more often. The positive qualities impacting the physiological well-being are following: sunlight being informative and with indications to change in season, for instance the first spring sun rays entering a North-East facing space; being a source of visual expression and wonder in the form of play of light and shadow, extending and decreasing the dimensions and depth of the architecture (Zakina, 2016), with the appearance of temporary light-zones (Madsen, 2006).

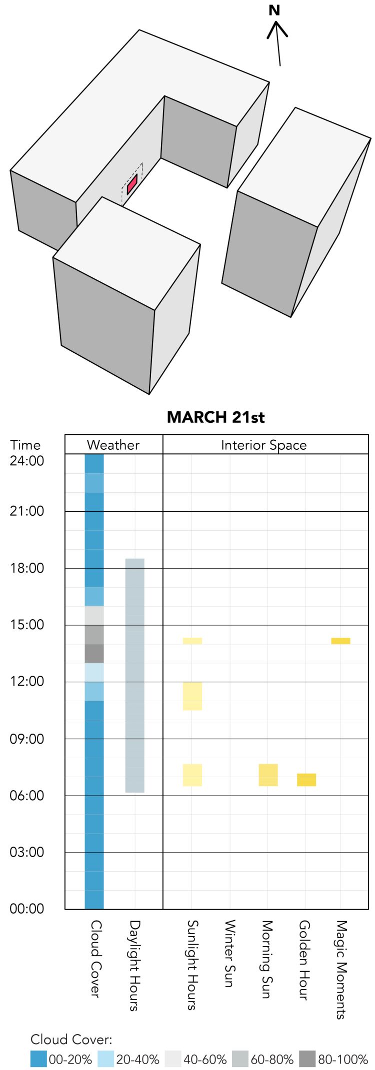
DEVELOPMENT AND IMPLEMENTATION

Analysis Tool

In order to make the sunlight qualities measurable, the five sunlight parameters were defined in relation to time continuum. All five sunlight parameters have the common factor, that they are originating from direct sunlight exposure, see the defined time periods for each parameter in the previous paragraph.

The purpose of the new analysis tool is to predict the timing and duration of each sunlight parameter for a chosen 3D model of a space to be analyzed during the course of one day (Figure 3). The tool was developed in a *Grasshopper/Ladybug/Honeybee* environment [6] for *Rhinoceros 3D* [8], which is an ideal setup for making custom made environmental analysis. In this stage, the tool is defined as a new framework within the Grasshopper environment. The tool is based on two existing Ladybug components: the *Ladybug_SunPath* and the *Ladybug_Sunlight Hours Analysis* [9]. As these components solely address solar geometry, two additional parameters were added to the new analysis tool: the daylight hours of the chosen day (21st of the month) and typical cloud coverage for the specific site on the specific month. By adding these, the five sunlight parameters can be re-

Figure 3
Demonstration of analysis output for a single day on a L-shaped building with South-East facing window and two tall obstructing buildings.



viewed in relation to the probable amount of sunlight hours for the given day and provide the best possible prediction of sunlight presence.

In general, the Ladybug Tools is intended for hourly based simulations, however intervals of one hour are not found suitable for the development of this tool. The primary purpose of the tool is not to quantify the amount of sunlight exposure, but to detect the timing and duration of the previously defined sunlight parameters, in order to enable a design method for dwellings, that truly enhances the dynamics of sunlight. A more frequent time step was necessary for detecting the brief occurrences of sunlight qualities, such as *Magic Moments* and *Golden Hour*. A calculation time step of 10 minutes was found suitable for the first four sunlight qualities, whereas a time step of 5 minutes is recommended for *Magic Moments*. These adjustments forlong the calculation time duration and therefore additional research should be conducted for further development of the tool.

The output of the analysis is comparable to a bar chart, illustrating the daylight hours, the probable cloud coverage and the five sunlight parameters on a timeline, representing one day (00:00 to 24:00). The result of the analysis is plotted for every timestep (10/5 minutes), thus the exact timing and duration of each sunlight parameter can be read from the graph.

To identify the five sunlight parameters in dwellings during a year, it is recommended to make an analysis for every single month. The 21st of every month was chosen in order to include the lowest and highest Sun elevation angle, during winter and summer solstice. In practice, calculations of only seven months are necessary, including solstices and the five mirrored months. Even though January and November are mirrored months, in terms of the perceived daylight hours, the cloud coverage for these months is to be presented according to the months, which shows variations. For instance, in Copenhagen on average in January the sky cloud coverage is 60-80%, whereas in November there is an increase, up to 80-100% in 1/3 of the time (Nielsen, 2018).

Implementation

The analysis tool was tested in collaboration with a major Danish building engineering consultancy company, Sweco Denmark A/S, applying the tool on a case study of a new apartment complex development in Copenhagen. Three almost identical 1-room apartments, on different floor levels and orientations were compared. The first apartment was placed on the ground floor with North-facing windows and an obstructing building of three-stories 25 meters away. The second apartment was placed on the first floor with windows towards West and with 20 meters distance to a three-story obstructing building. The third apartment was also placed on the first floor, with East-facing windows and without obstructing buildings within 50 meters distance. The aim was to demonstrate how different spaces performed in relation to the sunlight parameters with the various parameters. The output of the tool presented the timing and duration of the five sunlight parameters for each month and in addition the daylight hours and probable cloud coverage was presented.

The visualized analysis data enabled a more holistic understanding of the current daylighting conditions of the different apartments throughout an entire year. From visiting the construction site, a general understanding of the daylight intake and sunlight exposure were gained, in relation to window orientation, building geometry and obstructing buildings. However, the analysis tool provided more in-depth information about the sunlight exposure - especially the *Golden Hours* and *Magic Moments* were difficult to predict from the site visit. With the big seasonal changes in the solar path in Northern latitudes the *Morning Sun* can also be difficult to predict at site, as the azimuth angle at sunrise in Copenhagen varies from 43 degrees at summer solstice to 133 degrees at winter solstice [3].

Based on the analysis output for the case study, several design alterations for preliminary evaluations of the effectiveness of the tool were applied. In order to improve the possible exposure to the five sunlight parameters three design strategies were tested: altering the building orientation, introducing a terraced plan distribution of the apartments and increasing the depths of the existing window bays. The alterations showed promising improvements, however further research is proposed.

DISCUSSION

Further development of the tool

The five sunlight parameters, emerged from the qualitative analyses, can be questioned in terms of the scale of the study, analyses and the subjective interpretations. For instance, *Evening Sun* as a sunlight parameter was discussed, though discarded in the context of evaluating one-room apartments, as it can be argued to have a negative influence on circadian rhythm, especially for the elderly population. It is to be stated that the five sunlight parameters are proposed to be confirmed in extended qualitative research. Moreover, additional qualities could be detected in future work and elaborated in specific relation to room-types, for instance separating bedrooms and living rooms, serving different functions for the users.

For further development of the tool a few additional testing protocols are proposed including the possible new definitions of calculation surfaces, from one to several window openings combined and sunlight exposure detection on vertical and horizontal surfaces separately. These investigative developments could lead to additional sunlight parameters and qualities to be considered in the daylighting design.

In this project, the Danish daylight climate, standards and the dense urban context has set the focus. The adaptation of the tool beyond Nordic countries is found self-evident with an extension to neighboring countries, such as the Baltics, United Kingdom, Ireland and inclusion of parts of Canada and Russia in similar latitudes. The equivalent version of the tool for other climates and latitudes, however, would suggest further research and analyses, with elaborate knowledge.

The current demo version of the new analysis tool can be evaluated as difficult to navigate and the speed of calculations has not been addressed. The tool is therefore envisioned to be tested and optimized to become a new single component in the Ladybug environment, requiring minor software developments. This would enable the adaption of the tool in the daily workflow of architectural and engineering practices as well as with ease.

Potentials of the tool

The new analysis tool is predicted to be applicable in numerous ways. First of all, the analysis tool can be used to evaluate the performance of interior spaces in relation to the five sunlight parameters. In extension, the analysis output can be used to compare the performances of different design solutions and impact the decision-making in early stages of architectural developments. Ideally, the tool would be used as part of a performance-based design methodology, where the architectural form is gradually changed in relation to the analysis output in order to obtain a dynamic daylight design, including diverse sunlight exposure, for living environments.

As the analysis tool is developed in the *Grasshopper/Ladybug Tools* environment, the tool can be used simultaneously with standard daylight metrics such as the *Daylight Factor*, *spatial Daylight Autonomy* or *Useful Daylight Illumination*. The analysis tool exclusively addresses the positive effects of sunlight exposure, therefore the tool is envisioned to be used in combination with the *Annual Sunlight Exposure* metric and thermal calculations, in order to avoid excessive sunlight exposure and potential overheating.

One of the aims of the tool is to increase the awareness of the benefits and qualities of sunlight exposure for new homeowners. On real-estate websites today it has become common to include information about sun path, ground pollution, noise levels, risk of flood etc. Therefore, additional information and documentation about the sunlight qualities could be predicted to be beneficial to meet individual needs and preferences for daylight, as our daylight rhythms, habits, needs and work-life balance varies from person to person.

CONCLUSION

In this paper, we question: *how can qualities of Nordic sunlight in dwellings such as apartment buildings be defined? And how can these qualities subsequently be translated into a parametric analysis tool, with the aim of improving the daylight design of our homes?*

Taking a departure from phenomenological approach, qualitative research was conducted with the emphasis on subjective experiences, supported with literature research findings to identify qualities of direct sunlight in dwellings. These qualities were grouped into five sunlight parameters and defined in relation to time continuum and Sun position to make the immeasurable qualities into measurable numeric parameters to be developed and applied in *Grasshopper/Ladybug/Honeybee* environment for *Rhinoceros 3D*. The sunlight analysis tool enables not only a quantification of direct sunlight exposure, but also the exact timing and duration of the five sunlight parameters over a course of a year, presented in relation to daylight hours and standardized data of cloud coverage. The tool is especially suitable for detecting short occurrences of direct sunlight (*Magic Moments*) and sunlight exposure during transition hours, where the color of the sunlight changes to lower color temperatures, perceived as a change from yellow to reddish tones (*Golden Hours*).

This experimental approach enabled us to work with daylighting and sunlight in a new perspective. The sunlight analysis tool is envisioned to be implemented as a part of performance-based design methods with the emphasis on the human-centric design, harvesting the numerous benefits and qualities of sunlight. We hope to contribute to the design process of living environments that stimulate our psychical and psychological well-being in positive and sustainable ways.

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